A PARAMETER SENSITIVITY ANALYSIS ACROSS MESOSCALE BASINS ENTERING THE GULF OF MEXICO BASIN

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Executive Summary

Hydrologic models are tools that can quantify the natural flow regime for locations that lack pre-disturbed flow records by matching existing measurements and translating information from areas we have measurements to places that we don't. With any model application, we try to balance model complexity, the number of model parameters, with our ability to predict a range of hydrologic processes at fine scales. To address over-parameterization issues that arise from complex models, a sensitivity analysis can be employed to determine which parameters are more or less important.

The objective of this study is to understand unaltered drainages in the headwater basins of lower Alabama. To understand unaltered drainages we employed the Method of Morris sensitivity analysis for 7 headwater sites within the Gulf of Mexico Basin. At the headwater locations we used the Precipitation Runoff Modeling System (PRMS) model to simulate streamflow and compared to existing measurements. The importance of a model parameter was identified based on the mean (μ) and standard deviation (σ) across multiple elementary effects. By analyzing parameter sensitivity with respect to multiple metrics describing the flow regime, the sensitivity analysis allows us to rank the importance of the 17 model parameters and understand the dominant hydrologic process for unaltered drainages in headwater basins of lower Alabama.

In order to account for different flow regimes, performance of watershed models is often evaluated for multiple functions that capture different parts of the hydrograph. The evaluation functions focused on high flow, low flow, and daily flow.

Across the 7 mesoscale basins, we were able to identify the dominant parameters for the 6 different evaluation functions. The sensitivity analysis identified 8 PRMS model parameters as highly impactful on streamflow. These model parameters are associated with the soil-zone, subsurface, impervious zone, and the groundwater reservoir of the PRMS model. The main purpose of these parameters is to route water once it hits the land surface either to the stream network or through the soil profile into the groundwater reservoir are the controlling model parameters. Also, we were able to determine the parameters that were considered impactful were dominated by interactions. Due to the interactions, we have difficulty characterizing the model in terms of model parameters because multiple parameter sets are able to produce the same model output. Model interactions complicate the modeling effort and should be considered during calibration. Ultimately, a sensitivity analysis is able aid in model calibration by identifying impactful parameters and reducing the number of parameters to focus on during calibration.

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1.0 Introduction

Humans are responsible for altering the hydrologic cycle through land cover change (Sterling et al., 2012), construction and operation of dams (Fekete et al., 2010), and water withdrawals for agriculture and domestic/industrial use (Vörösmarty et al. 2000). These human alterations have transformed the landscape from natural conditions and caused changes in the water cycle. It is important for scientists and managers to understand the natural flow regime in order to quantify the effects of human alterations; however quantifying these effects can be a challenge (Arthington et al., 2006).

Hydrologic models are tools that can quantify the natural flow regime for locations that lack pre-disturbed flow records by matching existing measurements and translating information from areas we have measurements to places that we don't (Carlisle et al., 2010). With any model application, we try to balance model complexity, the number of model parameters, with our ability to predict a range of hydrologic processes at fine scales. There has been criticism that accounting for too many small-scale physical processes can lead to over-parameterization and equifinality (Beven, 1989, 1993). Over-parameterization involves using more parameters than necessary to obtain an output of interest (Beven, 1989). Equifinality is the concept that the same model output can be achieved through different combinations of parameter sets (Beven, 1993). Equifinality increases as the number of model parameters increase, because as the quantity of model parameters increase, a greater range of parameter values can create the same model output. Therefore, over-parameterization leads to equifinality

To address the over-parameterization and equifinality issues that arise from complex models, a sensitivity analysis can be employed to determine which parameters are more or less important. To do this, we applied a sensitivity analysis to determine how variability in parameters impacts the variability in the model output. The sensitivity analysis allows us to assess how parameters are impacting the model output, to focus on a few parameters and simplify modeling effort. By reducing the number of parameters we are able to potentially reduce equifinality and over-parameterization.

The objective of this study is to understand unaltered drainages in the headwater basins of lower Alabama. By predicting flow at unaltered drainages, we can use a trading space for time approach to understand how altered drainages have been changed. We use the general space for time substitution approach to understand previous conditions because we do not have historical datasets. Through evaluation and refinement of the model we are able to understand dominant hydrologic process, and the influences of difference changes on the model output. To understand unaltered drainages we employed the Method of Morris sensitivity analysis for 7 headwater sites within the Gulf of Mexico Basin simulating with the Precipitation Runoff Modeling System (PRMS) model. We investigated 17 different model parameters used during automated calibration by United States Geological Survey (USGS). It is important to note the model has other parameters; however, these parameters were not utilized during automated calibration or these parameters varied on a dimension other that hydrologic response units (HRUs) and therefore not considered for this study. The sensitivity analysis allows us to rank the importance of the 17 model parameters and understand the dominant hydrologic process for unaltered drainages in headwater basins of lower Alabama.

2.0 Study area and data

2.1 Description of the Gulf of Mexico Basin

The Gulf of Mexico Basin covers an area of approximately 13,383 mi^2 and encompasses a portion of Mississippi, Alabama, and Florida. The Gulf of Mexico River Basin is delineated by the Escatawpa River, Conecuh River, Pea River, and Choctawhatchee River. These rivers begin in Alabama and flow southwards. The Escatawpa River is an 80 mile long main tributary that feeds into the Pascagoula River that flows eventually to the Gulf of Mexico through the Mississippi Sound (Beckham III, 1977). The Conecuh River is a headwater river to the Escambia River that flows into the Gulf of Mexico through Pensacola Bay, which is connected to Escambia Bay (Lewis et al., 1998). The Pea River is a major tributary of the Choctawhatchee River (Fox et al., 2000). The Choctawhatchee River flows approximately 174 miles into the Choctawhatchee Bay, which is an inlet to the Gulf of Mexico (Fox et al., 2000) (Figure 1).

The Gulf of Mexico Basin has a variety of land cover types (Table 1). The dominant individual land cover is evergreen forest, followed by shrub/scrub (Table 1). On a broader sense, approximately 5 percent of the basin is classified as urban areas, 50 percent as forest, and 11 percent as wetlands (Hunt and Garcia, 2014).

Table 1. Summary of land cover classification for the Gulf of Mexico River Basin.

Class/Values	Classification	Percentages
11	Open Water	0.009
21	Developed, Open Space	0.048
22	Developed, Low Intensity	0.008
23	Developed, Medium Intensity	0.002
24	Developed, High Intensity	0.001
31	Barren Land	0.002
41	Deciduous Forest	0.084
42	Evergreen Forest	0.337
43	Mixed Forest	0.073
52	Shrub/Scrub	0.125
71	Herbaceous	0.020
81	Hay/Pasture	0.090
82	Cultivated Crops	0.088
90	Woody Wetlands	0.110
95	Emergent Herbaceous Wetlands	0.004

The entire study is composed of the Coastal Plain physiographic region. The Coastal Plain was created by sediment deposition from eroding mountain and Piedmont (Hupp, 2000). To further aid in model configuration, United States Environmental Protection Agency (USEPA) level IV ecoregions were considered as part of the regionalization approach. In particular, the physical similarity regionalization approach allows the parameter set from a calibration ecoregion be applied to ungauged basins within the same ecoregion (Arsenault and Brissette, 2014). The level IV ecoregions is a further subdivision of the landscape based on abiotic and biotic factors that affect ecosystem quality and integrity; these factors include geology physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Omernik, 1995). The Gulf of Mexico River Basin is composed of 8 ecoregions: Buhrstone/Lime Hills, Dougherty Plain, Floodplains and Low Terraces, Gulf Barrier Islands and Coastal Marshes, Gulf Coast Flatwoods, Southeastern Floodplains and Low Terraces, Southern Hilly Coastal Plain, and Southern Pine Plains and Hills. Description of these ecoregions can be found in Table 2.

Table 2. Description of level IV ecoregion present in Gulf of Mexico Basin.

Ecoregion	Description
Buhrstone/Lime Hills	Well-drained, loamy and sandy soils are typical on the narrow ridges and steep side slopes (Griffith et al., 2001).
Dougherty Plain	Influenced by the near surface limestone and the topography ranges from mostly flat to gently rolling (Griffith et al., 2001).
Floodplains and Low Terraces	Substrates of the low-relief region are a mix of sands, silts, and clays (Griffith et al., 2001).
Gulf Barrier Island and Coastal Marshes	Wet, sandy flat and broad depressions formed from delta deposits of Quaternary sands and clays (Griffith et al., 2001).
Southeastern Floodplains and Low Terraces	Riverine ecosystem comprised of large sluggish river and backwater with bonds, swamps, and oxbow lakes (Griffith et al., 2001).
Southern Hilly Gulf Coastal Plain	Diverse region of sand, clay, and marl formations, and the region has rolling topography, greater elevation and relief than Southern Pine Plains and Hill and Dougherty Plain (Griffith et al., 2001).
Southern Pine Plains and Hills	More resistant to erosion due to the Citronelle formation, which includes sandy, gravely, and porous substrate; due to the lack of erosion this ecoregion has hill summits and higher elevation (Griffith et al., 2001).

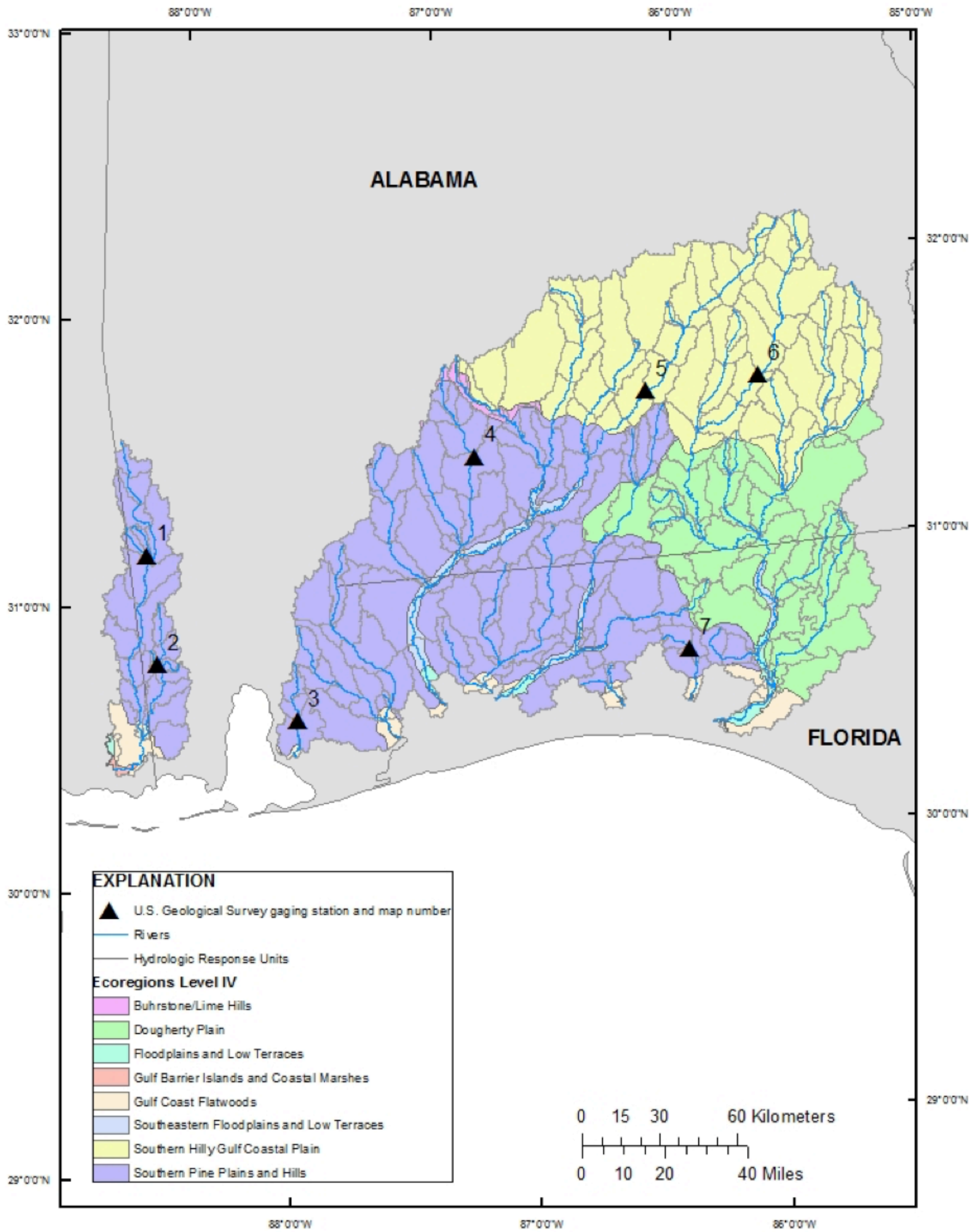

Figure 1. The location of the 7 streamflow gages used for the sensitivity analysis and the ecoregions present within the Gulf of Mexico Basin.

Table 3. U.S. Geological Survey streamflow gages used for first order stream reaches for automated calibration of the Gulf of Mexico Basin Precipitation-Runoff Modeling System model (Hunt and Garcia, 2014).

Map no.	Station name	Station number	Latitude	Longitude	Drainage area (mi^2)	Period of record
1	Pond Creek near Deer Park, Ala.	02479431	31°09'39"	88°21'43"	20.4	Oct. 1976–Sept. 1999
2	Crooked Creek near Fairview, Ala.	02479980	30°46'48"	88°19'08"	8.08	June 1990–present
3	Fish River near Silver Hill, Ala.	02378500	30°32'43"	87°47'55"	55.30	Dec. 1953–present
4	Murder Creek near Evergreen, Ala.	02374500	31°25'06"	86°59'12"	176.00	Mar. 1938–present
5	Conecuh River at Brantley, Ala.	02371500	31°34'24"	86°15'06"	500.00	Mar. 1938–present
6	Pea River near Ariton, Ala.	02363000	31°35'41"	85°46'59"	498.00	Mar. 1939–present
7	Alaqua Creek near Pleasant Ridge, Fla.	02366996	30°40'08"	86°11'12"	39.1	Oct. 1998–Dec. 2011

3.0 The Precipitation Runoff Modeling System

3.1 Description of PRMS

The Precipitation Runoff Modeling System (PRMS) (Leavesley et al., 1983; Markstrom et al., 2008) is surface water driven, deterministic and spatially explicit model developed by the USGS National Research Program. The model requires multiple data sources for configuration and calibration, and these include: streamflow, climate, and spatially distributed geographic information system (GIS) layers. The streamflow data required for calibration to the Gulf of Mexico basin utilized at least 10 years of continuous recorded discharge data from nineteen USGS streamgaging stations (Table 3). Since the goal was to create a hydrologic model that simulated a natural flow regime it was important to selected streamgages that had little human disturbance (Falcone et al., 2010). Also, the PRMS model requires maximum and minimum temperature and precipitation. To meet the PRMS climatological data needs we used the Daymet dataset to force the meteorological conditions. Daymet, from the National Aeronautics Space Administration (NASA) is an interpolation of daily meteorological observations to produce gridded estimates (Thornton et al, 2012). The gridded estimates provided precipitation and maximum and minimum temperature time series. These estimates are provided at a 1 km spatial resolution; the resolution is fine enough to produce precipitation and temperature values at different elevations (Young et al., 2009).

The model's geospatial framework was based on spatially distributed GIS layers, which includes National Elevation Dataset (NED), State Soil Geographic (STATSGO), and 2001 National Land Cover Database (NLCD). The geospatial framework delineated watersheds, divided the model into hydrologic response units (HRUs), and provided input parameter values. The Gulf of Mexico Basin had a total of 438 HRUs.

Model configuration was based on the geospatial framework and level IV ecoregions (Griffith et al., 2001). In order to distribute parameters to ungaged location, we used the physical similarity regionalization approach based on level IV ecoregions. Other studies have suggested that ecoregions are useful for simulating a natural flow regime (Carlisle et al., 2010). Therefore, for the purpose of the Gulf of Mexico calibration scheme, model parameters were calibrated to undisturbed gaging stations and then those calibrated parameters were applied to ungaged subbasins in the same ecoregion (Hunt and Garcia, 2014). This calibration technique allowed us to create a model for ungaged areas that are disturbed.

Prior to this current study, we calibrated the model using Let Us CAlibrate (LUCA), a multi-objective, stepwise automated calibration scheme for the PRMS model (Hay and Umemoto, 2007). Each multi-objective function calibrated a certain set of parameters through the shuffled complex evolution (SCE) global search algorithm (Duan et al, 1994). The purpose of the automated calibration for the Gulf of Mexico PRMS model, the multi- functions of interest were: water balance, daily flow timing for all flows, daily flow timing for high flows, daily timing for low flows, and the daily flow timing of all flows again (Table 2). The function was evaluated based on the normalized root-mean-square error (NRMSE) statistics.

3.2 PRMS components

PRMS implements the USGS Modular Modeling System (MMS) (Leavesley et al., 1996) to simulate different processes. The hydrologic processes are predicted by changing model parameters in order to minimize the water balance error between the simulated and observed streamflows. The different hydrologic processes simulated within the modular system include: interception, rainfall or snow, infiltration, surface storage, depression storage, subsurface flow, interflow and groundwater flow. The plant canopy interception module computes the amount of rain that is intercepted by the vegetation cover density. Evaporation and sublimation are contributing processes that control interception. The total amount of precipitation delivered to land surface is considered net precipitation. The snowpack modular simulates the accumulation and release of a snowpack on each HRU. The net precipitation in the form of snow that reaches the snowpack melts, evaporates, or sublimates from the snow surface. The water that melts eithers infiltrates the soil or reaches impervious surface.

Below ground, the soil-zone reservoir represents exposed soil that can lose water through evaporation and transpiration. The soil-zone reservoir is composed of two parts, the recharge zone and the lower zone. The soil-zone reservoir gains water through net precipitation in the form of snow and rain and the reservoir losses water through evapotranspiration. The net precipitation infiltrates the recharge zone and then moves to the lower zone. Once the soil-zone reservoir is full, the excess water is routed to the subsurface and groundwater reservoir.

In areas with impervious surface, net precipitation reaches the surface and then flows over the land surface towards the stream network. Some of this water will be lost due to evaporation or areas of depressions. The remaining water will reach the stream network. Depression storage accounts for the water that is retained in surface pits and depressions, which gain water from surface runoff. Once depressions are full, the excess water flows into the stream network. The depressions can also lose water through groundwater seepage to the groundwater reservoir.

The surface reservoir simulates the relatively fast flow component of the saturated-unsaturated and groundwater zones. The subsurface reservoir gains water through excess water from the soil-zone reservoir and loses water to the groundwater reservoir and the stream network through gravity and preferential flow. Movement of water to the groundwater reservoir is a slower process. Water reaches the groundwater reservoir from the excess water from the soil-zone reservoir, and seepage from depression storage and the subsurface reservoir. The groundwater reservoir contributes water to the stream network and the deep aquifer.

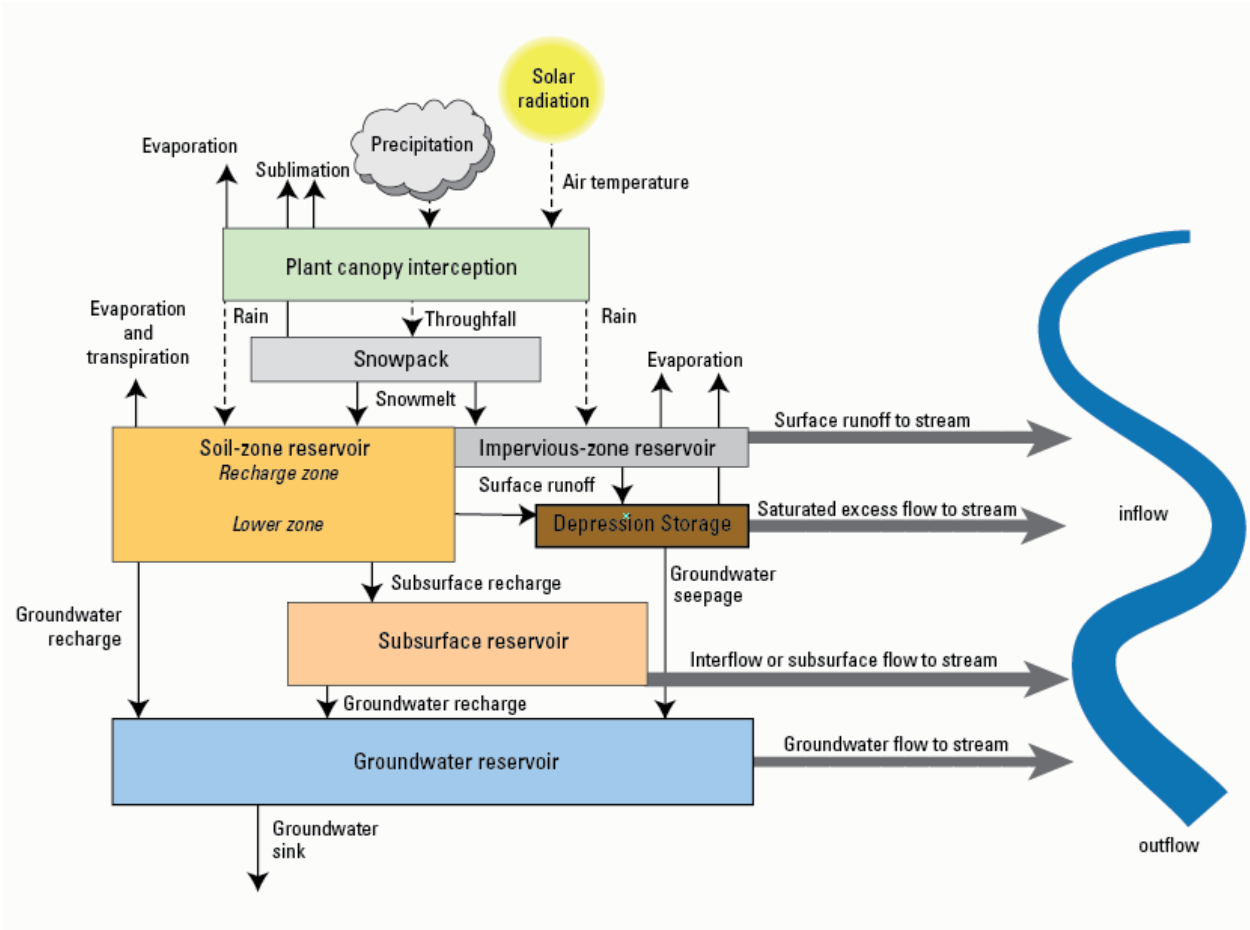

Figure 2. Modular Modeling System schematic of the Precipitation-Runoff Modeling System (Markstrom et al., 2008).

3.3 PRMS Parameters

The PRMS automated calibration strategy focused on 17 model parameters that were calibrated based on HRUs. Within this strategy there were four different functions that emphasized three different flow regimes (daily, high, and low). Table 4 documents the 17 model parameters, parameter names, and descriptions.

Table 4. Description of parameters evaluated using the Method of Morris sensitivity analysis.

Parameter Number	Objective Function	PRMS parameters adjusted	Parameter description	Parameter range
1	Daily flow timing (all flows)	slowcoeflin	Linear coefficient in equation to route gravity-reservoir storage down slope for each HRU	0.001–0.5
2	Daily flow timing (all flows)	soilmoistmax	Maximum available water holding capacity of soil profile	2.0–10.0
3	Daily flow timing (all flows)	soilrehrmax	Maximum available water holding capacity for soil recharge zone	1.5–5.0
4	Daily flow timing (high flows)	fastcoeflin	Coefficient to route preferential-flow storage down slope	0.001–0.8
5	Daily flow timing (high flows)	prefflowden	Faction of soil zone in which preferential-flow occurs	0–0.1
6	Daily flow timing (high flows)	satthreshold	Water holding capacity of the gravity and preferential-flow reservoirs	1.0–15.0
7	Daily flow timing (high flows)	smidxcoef	Coefficient in non-linear surface runoff contributing area algorithm	0.0001–0.06
8	Daily flow timing (low flows)	gwflowcoef	Linear coefficient to compute groundwater discharge form each GWR	0.001–0.5
9	Daily flow timing (low flows)	soil2gwmax	Maximum amount of capillary reservoir excess routed directly to the GWR	0.0–0.5
10	Daily flow timing (low flows)	ssr2gwrate	Linear coefficient used to route water from the gravity reservoir to the GWR	0.05–0.8
11	Daily flow timing (all flows)	dprstdepthavg	Average depth of depressions at maximum storage capacity	48–250
12	Daily flow timing (all flows)	dprstflowcoef	Coeffcient in linear flow routing equation for open surface depressions	0.001–0.3
13	Daily flow timing (all flows)	dprstfracint	Fraction of maximum storage capacity	0.0–1.0
14	Daily flow timing (all flows)	dprstseeprateopen	Coefficient used in linear seepage flow equation for open surface depressions	.0005–0.01
15	Daily flow timing (all flows)	srotodprst	Fraction of pervious and impervious surface runoff that flows into surface depressions	0.0–1.0
16	Daily flow timing (all flows)	vaopenexp	Coefficient to control shape of depressions	0.001–1.0
17	Daily flow timing (all flows)	opflowthres	Fraction of open depression storage above which surface runoff occurs for each timestep	0.75–0.01

The model parameters are used to simulate different hydrologic processes for the PRMS modules. Four of the 17 parameters are used to simulate the subsurface modular. Subsurface parameters focus on routing gravity and preferential flows (slowcoeflin,fastcoflin,prefflowden, and satthreshold). Three of the 17 parameters are used to represent the water holding capacity of the soil and the routing of water from the soil into the groundwater (soilmoistmax, soilrehrmax, and soil2gwmax). One parameter characterizes the contribution of runoff from impervious land surface (smidxcoef). Seven parameters simulate the storage capacity, contribution to stream network, and routing of water into depressions (dprstdepthavg, dprstflowcoef, dprstfracint, dprastseeprateopen, srotodprst, vaopenexp, and opflowthers). Overall the 17 parameters are used to simulate multiple hydrologic processes, which are associated with different modules of the PRMS model.

4.0 Sensitivity Analysis

Sensitivity analysis provides an understanding of the relationship between the model parameters and model output (McCuem, 1973). For environmental modeling, sensitivity methods are classified by two techniques, local and global. Local techniques evaluate one parameter at a time, while the global technique evaluates the sensitivity over the entire user defined parameter space (Van Griensven et al., 2006). Ideally, global techniques are applied because they evaluate the parameters sensitivity and the interactions between parameters; however global techniques require a high number of evaluations for every increase in the number of parameters (Campolongo et al., 2007). In contrast, local techniques vary one parameter and are unable to determine the effect of interaction between parameters.

4.1 Method of Morris

The Method of Morris (Morris, 1991) is an integration of multiple local sensitivity experiments to characterize global sensitivity (Van Griensven et al., 2006). The method is based on the one-at-a-time (OAT) method, in which a parameter is varied along a grid size of Δ_i (Herman et al., 2013). It evaluates the elementary effect (EE) of an i-th parameter by:

$$EE_i = \frac{[y(x_{1,}x_{2,},\ldots,x_{i-1}, x_i + \Delta_i, x_{i+1,},\ldots,x_k) - y(x)]}{\Delta_i} \qquad (1)$$

where y is the model output, x_i is the varying parameter value, and Δ_i is the grid size used to create parameter space. The Method of Morris completes multiple EE experiments to create trajectories. These trajectories provide an understanding about how changing the parameter value and other parameters impact the model output. Following the trajectories from multiple EEs we are able to calculate the mean and standard deviation sensitivity indices for each model parameter. The mean indicates the importance of the parameter on the output, and the standard deviation indicates the level of interaction between the parameter and other parameter values (Morris, 1991).

The sensitivity analysis focused on the 17 parameters from the PRMS automated calibration scheme. We distributed these parameters based on HRUs, but also on ecorgions. To evaluate 17 parameter values, we used the Method of Morris within the Sensitivity Analysis for Everyone (SAFE) Toolbox (Pianosi et al., 2015). SAFE is an open source Matlab toolbox to assess and visualize the robustness and convergence of sensitivity analysis (Pianosi et al., 2014). SAFE is divided into three steps: sampling input space, model evaluation, and post-processing. The sampling input space step utilized the Sobol's sampling strategy, in which the number of model evaluations required was computed by

$$N= (i+1) * r \tag{2}$$

where i is the number of parameters, and r is the number of sampling points. We selected an r value of 30, which an average number of sampling points. As compared to other studies, r can range between 10 to 50 (Campolongo et al., 2007; Herman et al., 2013). A larger r value provides more reliability because the number of model evaluations increase in response. However, increasing r requires a greater run time for the Sobol's sampling strategy. Based on evaluating 17 parameters and an r value of 30, 540 model evaluations were required for each individual station.

4.2 Model output metrics

For this study, 6 functions were evaluated to determine the sensitive parameters for different types of flows. In order to account for different flow regimes, performance of watershed models is often evaluated for multiple functions that capture different part of the hydrograph (Gupta et al., 1998). The 6 functions include root mean square error (RMSE), transformed root mean square error (TRMSE), error of the 50% lowest flow exceedance, error of 10% highest flows exceedance, error of daily flows, and coefficient of determination (R^2). RMSE and error of 10% highest flows exceedance functions evaluate the high flow regime, TRMSE and error of the 50% lowest flow exceedance functions evaluate the low flow regime, and error of daily flows and R^2 functions evaluate daily timing. The values are calculated from the difference between simulated and observed stream flow for different parts of the hydrograph.

The error of the 50% lowest flow exceedance, error of 10% highest flows exceedance, and error of daily flows functions are based on the Expert System for the Calibration of Hydrologic Simulation Program (HSPEXP) model performance criteria (Lumb et al, 1994). HSPEXP compared simulated and observed data for different flow regimes. The error of the 50% lowest flow exceedance (Equation 3) evaluates the error in low flows, and is defined as

$$f_l(\theta) = [(EX_{obs,50\%\ lowest\ flow} - EX_{sim,50\%\ lowest\ flow}) / (EX_{obs,50\%\ lowest\ flow})] * 100 \tag{3}$$

where EX is the fraction of time stream flow is less than or equal to the 50% exceedance flow rate (Kim et al., 2007). The error of 10% highest flows exceedance (Equation 4) focuses on high flows, and is defined as

$$f_h(\theta) = [(EX_{obs,10\%\ highest\ flow} - EX_{sim,10\%\ highest\ flow}) / (EX_{obs,10\%\ highest\ flow})] * 100 \quad (4)$$

where EX is the fraction of time that stream flow equals or exceeds the 90% exceedance flow rate (Kim et al., 2007). The error of daily flows (Equation 5) focuses on total volume, and is defined as

$$f_d(\theta) = [(Q_{obs} - Q_{sim}) / (Q_{obs})] * 100 \quad (5)$$

where Q is daily flow (Kim et al., 2007). A value of 0% indicates there is no difference between the simulated and observed stream flow, and any value above 10% is above recommended criteria (Lumb et al, 1994). Other hydrologic models consider RMSE, TRMSE, and R^2 as important statistical evaluations that capture watershed behavior (van Werkhoven et al., 2008; Wagener et al, 2009; Cibin et al., 2013). RMSE is considered a high flow function and is defined as

$$RMSE = \sqrt{\frac{1}{m}\sum_{t=1}^{m}(Q_{s,t} - Q_{o,t})^2} \quad (6)$$

where m is the number of time steps, $Q_{s,t,}$ is the simulated flow at time step t, and $Q_{o,t,}$ is the observed flow at time step t (Wagener et al, 2009). An ideal RMSE value would be 0, and the range of acceptable RMSE values depends on the high flow stream flow rates. We also evaluated TRMSE, a low flow function. Before TRMSE can be computed a Box-Cox transformation (Equation 7) must be performed on the observed and simulated flow time series. For the Box-Cox transformation we assumed a λ value of 0.3, as noted in other studies (van Werkhoven et al., 2008). The Box-Cox transformed observed and simulated time series were applied in the TRMSE calculation (Equation 8),

$$Z = \frac{(1+Q)^{\lambda}-1}{\lambda} \quad (7)$$

$$TRMSE = \sqrt{\frac{1}{m}\sum_{t=1}^{m}(Z_{s,t} - Z_{o,t})^2} \quad (8)$$

where m is the number of time steps, $Z_{s,t}$ is the Box-Cox transformed simulated flow time series, and $Z_{o,t}$ is the Box-Cox transformed observed flow time series (van Werkhoven et al., 2008). An ideal TRMSE value would be 0, and the range of acceptable TRMSE values depends on the low flow stream flow rates. The final function considered was the coefficient of determination (R^2). R^2 is given by

$$R^2 = \left\{\frac{\sum_{i=1}^{N}(Q_{obs,i}-\bar{Q}_{obs})(Q_{sim,i}-\bar{Q}_{sim})}{\left[\sum_{i=1}^{N}(Q_{obs,i}-\bar{Q}_{obs})^2\right]^{0.5}\left[\sum_{i=1}^{N}(Q_{obs,i}-\bar{Q}_{obs})^2\right]^{0.5}}\right\}^2 \quad (9)$$

where N is the number of time steps, Q is the daily flow, and the bar denotes the mean for the entire period (Kim et al., 2007). An ideal R^2 is 1, and the any R^2 above 0.5 is considered within calibration criteria. These 6 functions quantify different flow regimes, which allow us to assess parameter sensitivities to different flow regimes.

5.0 Results

The model was run for the same time period of model calibration as for the Alabama PRMS natural flow study (Hunt and Garcia, 2014). This required the calibration stations to be analyzed for different time periods, based on available stream flow data. USGS streamgaging stations 02363000, 02371500, 02374500, 02378500, and 02479980 were analyzed from October 1st, 1999 through September 30th 2008. USGS streamgaging station 02366996 was analyzed from October 1st, 2000 through September 30th, 2008 and USGS streamgaging station 02479431 was analyzed from October 1st, 1990 through September 30th, 1999. The Method of Morris was performed at all 7 of these stations, to evaluate the sensitivity of the output to 17 model parameters. The parameters that were able to be distinguished from the parameter set (n=580) were documented as significant to the model output.

The importance of a model parameter was identified based on the mean (μ**)** and standard deviation (σ) across multiple EEs. The MoM is considered a rank based tool; therefore, the μ and σ of the elementary effect were visually ranked as either having high, medium, low, and no impact on model output. Section 5.1 discusses the results on the MoM for each individual station independently. Then section 5.2 identifies of important parameters across mesoscale basins.

5.1 Station Evaluation

Results for Crooked Creek near Fairview, AL. (02479980)

The results of the Method of Morris global sensitivity performed at USGS streamgage station Crooked Creek near Fairview, AL (02479980) are shown in Figure 3, Figure 4, and Appendix A1. The μ sensitivity index for all the function (Figure 3A; Figure 3B; Figure 3C; Figure 3D; Figure 3E; Figure 3F) highlighted the water holding capacity of soil profiles parameter (soilmoistmax) had medium or low impact. No other parameters had sensitivity for every function.

The μ sensitivity index for the daily flow error (Figure 3A) and R^2 (Figure 3D) illustrate that the parameter that characterizes the non-linear coefficient controlling surface runoff (smidx_coef) had the largest impact predicting daily model output. Also, this coefficient is highly influenced by other parameters (Figure 4A and 4D). The two daily flow functiosn show different results on the parameters considered to have low impact. The preferential flow pore density parameter (prefflowden) and multiple depression storage parameters (dprstdepthavg, dprstfracint, dprstseeprateopen, and vaopenexp) had low impact on the daily flow error (Figure 3A). A coefficient to compute groundwater discharge to the streamflow (gwflowcoef) had low impact on the R^2 metrics (Figure 3D). In total, nine parameters had no impact on either daily flow function.

Different parameters control the two high flow functions, the error of 10% highest flow exceedance function (Figure 3B) and RSME fucntion (Figure 3E). The fraction of surface area that are open to surface depressions (vaopenexp) had a high impact on 10% highest flow exceedance function (Figure 3B), and no impact on the RMSE function. Also, the 10% highest flow exceedance function (Figure 3B) highlights that fast flow parameters (factcoeflin and prefflowden) and depression storage parameters (dprstdepthavg, dprstfracint, dprstseeprateopen, and srotodprst) had medium to low impact. The depression storage and fast flow parameters had little impact on the RMSE function (Figure 3E). The coefficient to obtain groundwater flow contributing to streamflow (gwflow_coef) had a high impact on the RMSE function, and medium impact on the 10% highest flow exceedance function.

Different parameters influence the two low flow functions, the error of 50% lowest flow exceedance function (Figure 3C) and TRSME function (Figure 3F). The coefficient to obtain groundwater flow contributing to streamflow (gwflow_coef) had a high impact on the error of 50% lowest flow exceedance function (Figure 3C). In contrast, the TRMSE function (Figure 3F) was most sensitive to the coefficient to control shape of depressions (vaopenexp). TRSME function (Figure 3F) illustrates fast flow parameters (fastcoeflin and prefflowden) and the coefficient to obtain groundwater flow contributing to streamflow (gwflow_coef) had medium impact. Also, TRMSE highlights depression storage parameters (dprstdepthavg, dprstfracint, dprstseeprateopen, and srotodprst) to have low impact.

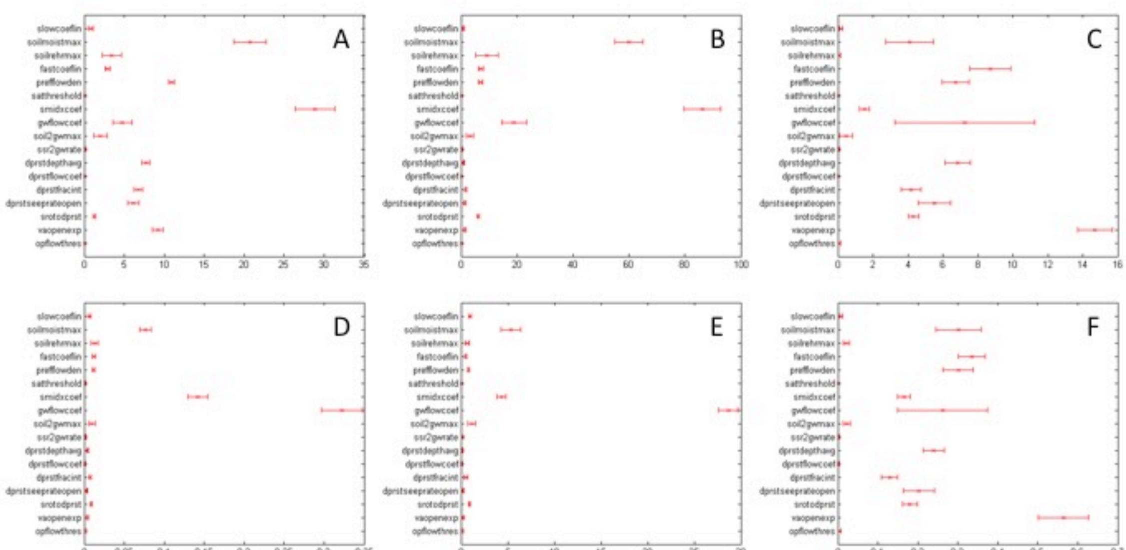

Figure 3. Function evaluation of the mean EE at Crooked Creek near Fairview, AL (USGS streamgage 02479980).

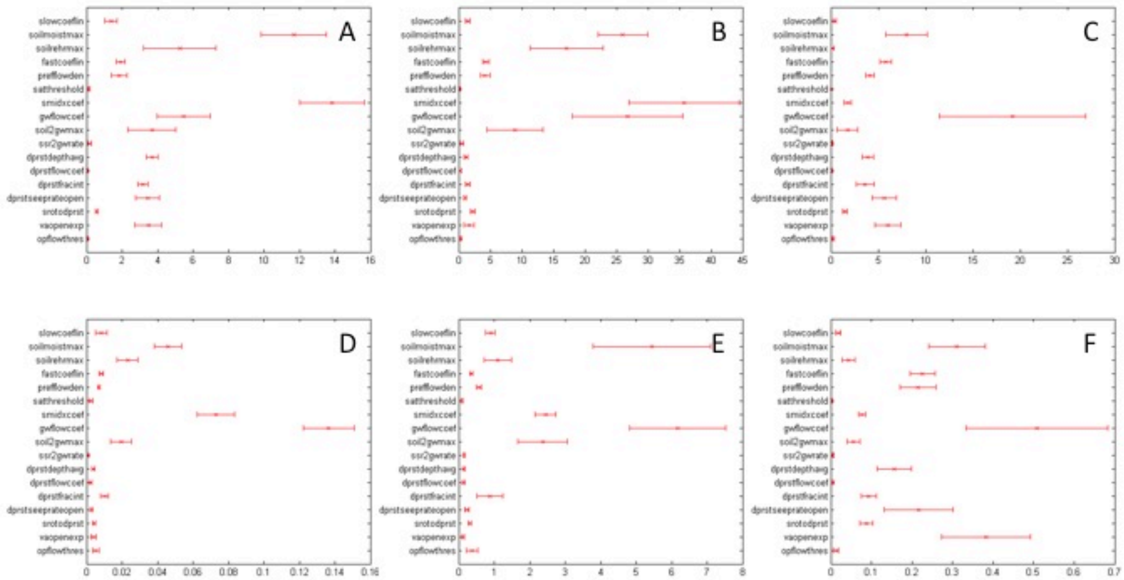

Figure 4. Function evaluation of the standard deviation EE at Crooked Creek near Fairview, AL (USGS streamgage 02479980).

Results for Pea River near Ariton, AL. (02363000)

The results of the Method of Morris global sensitivity performed at USGS streamgage station Pea River near Ariton, AL. (02363000) are shown in Figure 5, Figure 6, and Appendix A2. The μ sensitivity index for all the function (Figure 5A; Figure 5B; Figure 5C; Figure 5D; Figure 5E; Figure 5F) highlighted the water holding capacity of soil profiles parameter (soilmoistmax) and non-linear coefficient controlling surface runoff (smidx_coef) parameters had high or medium impact. These two parameters were the only ones that had sensitivity for every function.

The μ sensitivity index the daily flow error (Figure 5A) and R^2 (Figure 5D) illustrate that preferential-flow pore density (prefflowden) had medium impact on the daily flow error output (Figure 5A) and no impact on the R^2 function (Figure 5D) output. The coefficient to compute groundwater discharge to the streamflow (gwflowcoef) had medium impact on the R^2 function (Figure 5D) and no impact on the daily flow error function (Figure 5A). The water holding capacity of the soil recharge zone parameter (soilrehrmax) had low impact on the daily flow error (Figure 5A) and R^2 (Figure 5D) functions.

The coefficient to compute groundwater discharge to the streamflow (gwflowcoef) had medium impact on the RMSE function (Figure 5E) and low impact on the error of 10% highest flow exceedance function (Figure 5B). The route gravity-flow down slope parameter (slowcoeflin), water holding capacity of soil recharge zone (soilrehrmax), fast flow (fastcoflin and prefflowden), and the soil water excess routed to groundwater reservoir (soil2gwmax) parameters had low impact on the RMSE function (Figure 5E) and no impact on the error of 10% highest flow exceedance function (Figure 5B) output.

The coefficient to compute groundwater discharge to the streamflow (gwflowcoef) had high impact on the error of 50% lowest flow exceedance output (Figure 5C) and low impact on TRMSE output (Figure 5F). The parameter that routes preferential-flow down slope (fastcoeflin) had medium impact on 50% lowest flow exceedance (Figure 5C) and TRMSE (Figure 5F) output. The preferential-flow pore density parameter (prefflowden) had medium impact on 50% lowest flow exceedance output (Figure 5C) and low impact on the TRMSE output (Figure 5F). The water holding capacity of the soil profile parameter (soilrehrmax) had little impact on the TRMSE output (Figure 5F) and no impact on the 50% lowest flow exceedance output (Figure 5C). The soil water excess routed to the groundwater reservoir parameter (soil2gwmax) had little impact on 50% lowest flow exceedance output (Figure 5C) and no impact TRMSE output (Figure 5F).

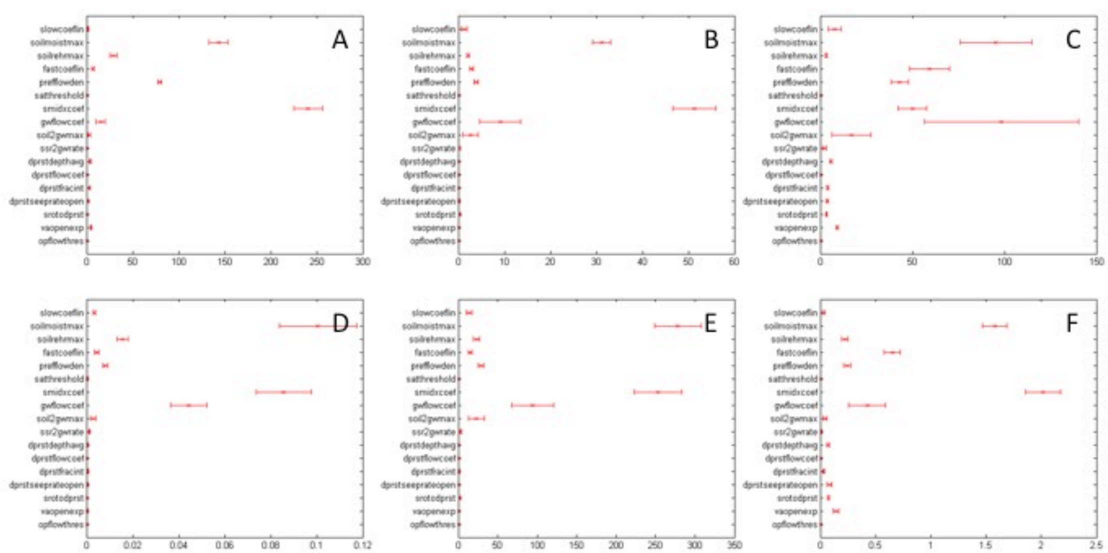

Figure 5. Function evaluation of the mean EE at Pea River near Ariton, AL. (USGS streamgage 02363000).

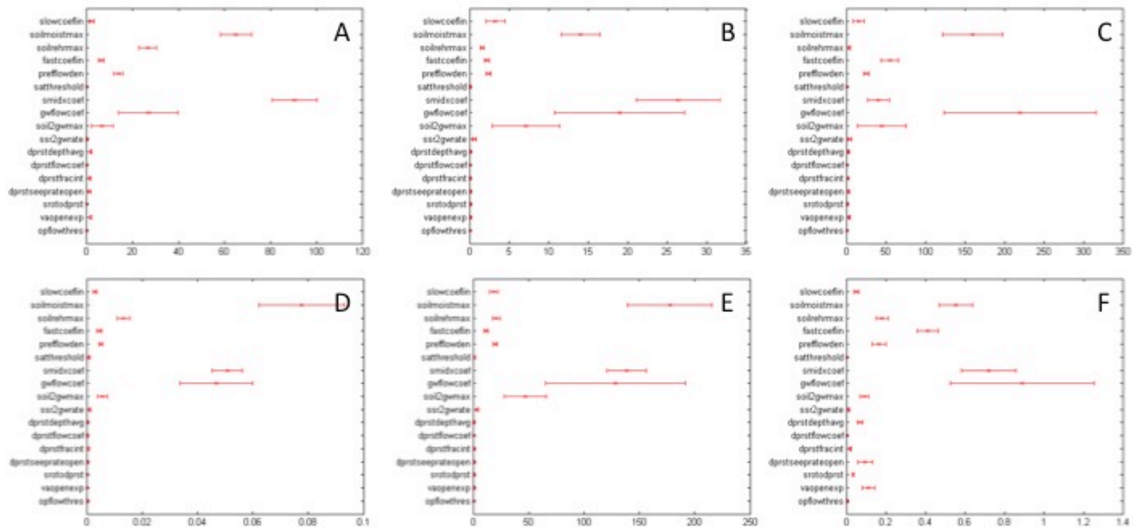

Figure 6. Function evaluation of the standard deviation EE at Pea River near Ariton, AL. (USGS streamgage 02363000).

Results for Conecuh River at Brantley, AL. (02371500)

The results of the Method of Morris global sensitivity performed at USGS streamgage station Conecuh River at Brantley, AL. (02371500) are shown in Figure 7, Figure 8, and Appendix A3. 7 parameters had sensitivity to all 6 functions (Figure 7A; Figure 7B; Figure 7C; Figure 7D; Figure 7E; Figure 7F). The parameter for water holding capacity of the soil profile (soilmoistmax) had high or medium impact on all functions. The groundwater flow into streams parameter (gwflowcoef) parameter and the non-linear coefficient controlling surface runoff (smidxcoef) ranged from low to high impact across the functions. The preferential-flow pore density (preflowden) parameter and the routing preferential-flow down slope (fastcoeflin) parameter had medium or low impact on all functions. The parameters associated to route gravity-flow down slope (slowcoeflin) and soil water excess routed to groundwater reservoir (soil2gwmax) had little impact on all 6 metrics.

Two other parameters had sensitivity to some function and not to other functions. The parameter to route gravity-flow down slope (soilrehrmax) had low impact on the daily functions and the high function, four functions in total (Figure 7A; Figure 7B; Figure 7D; Figure 7E). The parameter that characterizes the fraction of surface area that is open to depression (vaopenexp) had low impact on the TRMSE output (Figure 7F).

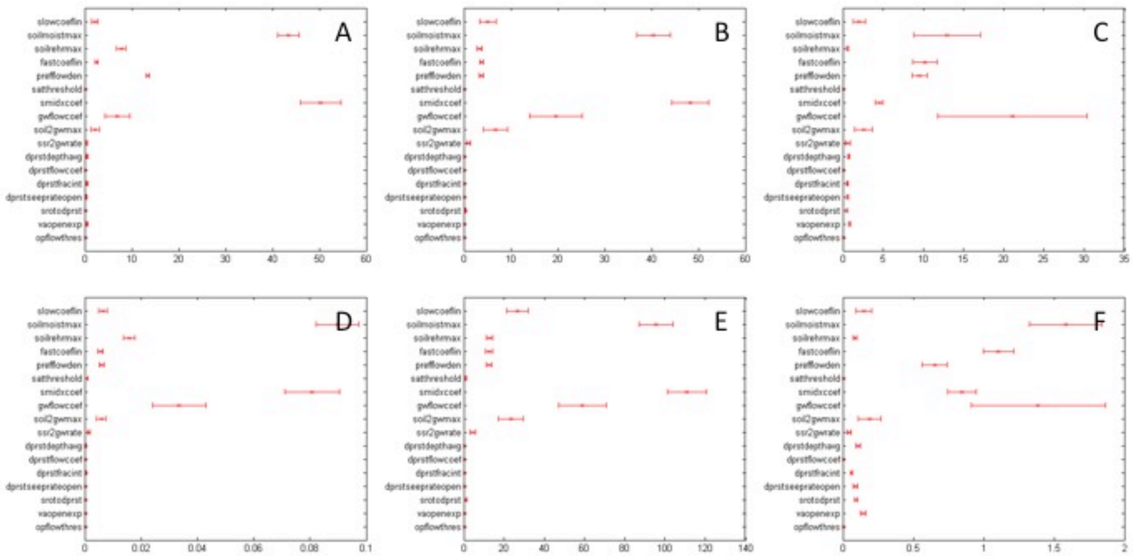

Figure 7. Function evaluation of the mean EE at Conecuh River at Brantley, AL. (USGS streamgage 02371500).

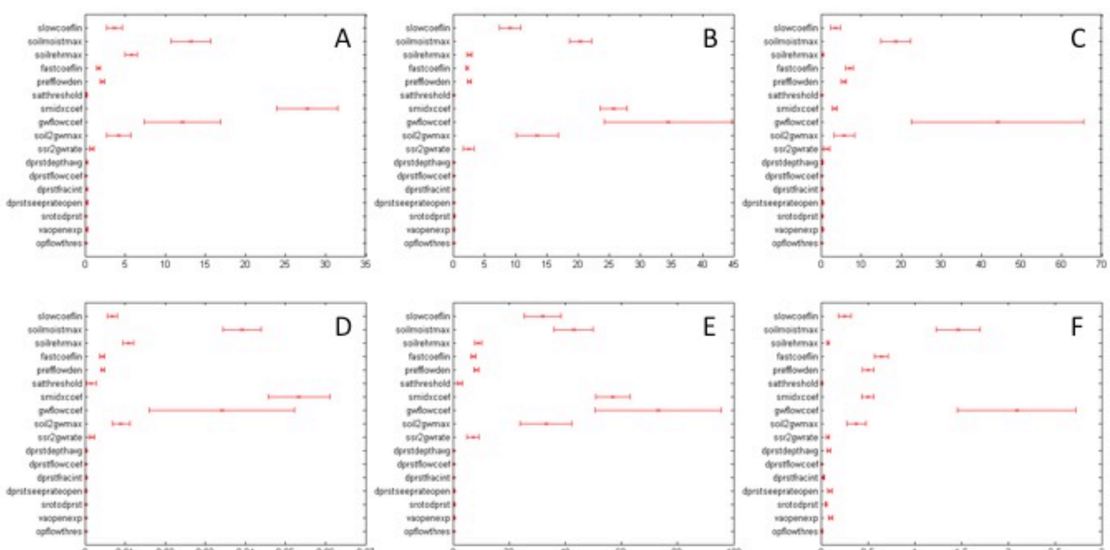

Figure 8. Function evaluation of the standard deviation EE at Conecuh River at Brantley, AL. (USGS streamgage 02371500).

Results for Conecuh River at Alaque Creek near Pleasant Ridge, FL. (02366996)

The results of the Method of Morris global sensitivity performed at USGS streamgage station Alaque Creek near Pleasant Ridge, FL (02366996) are shown in Figure 9, Figure 10, and

Appendix A4. The μ sensitivity index highlighted five parameters impacted all functions, and two parameters impacted five out of the 6 functions (Figure 9A; Figure 9B; Figure 9C; Figure 9D; Figure 9E; Figure 9F). The water holding capacity of soil profile parameter (soilmostmax), the non-linear coefficient controlling surface runoff parameter (smidxcoef), and groundwater flow into the stream network parameter (gwflowcoef) had high or medium impact across all functions. The parameter that routes gravity-flow down slope (slowcoeflin) and soil water excess routed to the groundwater reservoir (soil2gwmax) parameters had medium or low impact on all functions. The parameter that characterizes the preferential-flow pore density (prefflowden) and the routing preferential-flow down slope (fastcoeflin) parameter had medium or low impact on all functions except the R^2 function, where it had no impact.

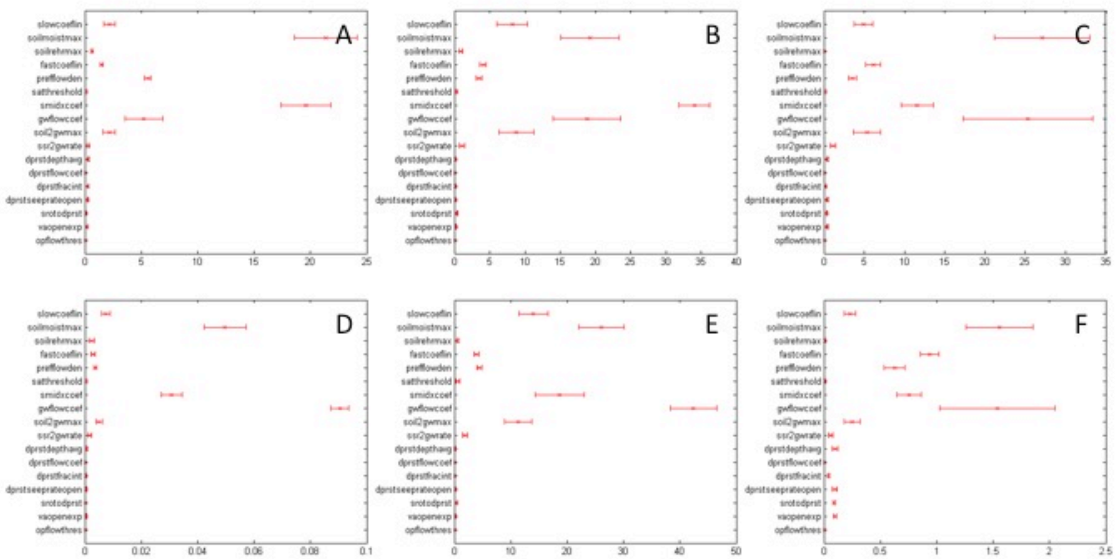

Figure 9. Function evaluation of the mean EE at Alaque Creek near Pleasant Ridge, FL. (USGS streamgage 02366996).

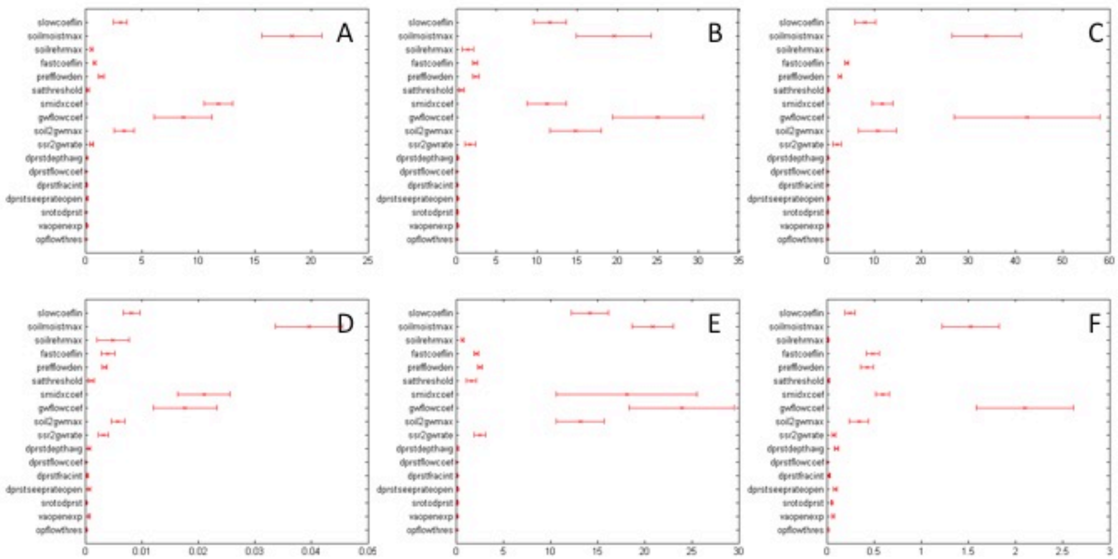

Figure 10. Function evaluation of the standard deviation EE at Alaque Creek near Pleasant Ridge, FL. (USGS streamgage02366996).

Results for Conecuh River at Pond Creek near Deer Park, AL. (02479431)

The results of the Method of Morris global sensitivity performed at USGS streamgage station Pond Creek near Deer Park, AL. (02479431) are shown in Figure 11, Figure 12, and Appendix A5. The μ sensitivity index highlighted 6 parameters impacted all functions, one parameter impacted five out of 6 functions, and one parameter impacted four out of 6 functions (Figure 11A; Figure 11B; Figure 11C; Figure 11D; Figure 11E; Figure 11F). The water holding capacity of soil profile parameter (soilmostmax), and groundwater flow into the stream network parameter (gwflowcoef) had high or medium impact across all functions. The non-linear coefficient controlling surface runoff parameter (smidxcoef) had sensitivity ranging from low to high across the functions. The routing preferential-flow down slope (fastcoeflin) parameter had medium or low impact on all functions. The parameters that route gravity-flow down slope (slowcoeflin) and soil water excess routed to groundwater reservoir (soil2gwmax) had little impact on all 6 metrics. The parameter that characterizes the preferential-flow pore density (prefflowden) had medium or low impact on all functions except the daily flow error function. The water holding capacity of the soil recharge zone parameter (soilrehrmax) had medium or low impact on all function except the 10% highest flow exceedance function (Figure 11B) and the

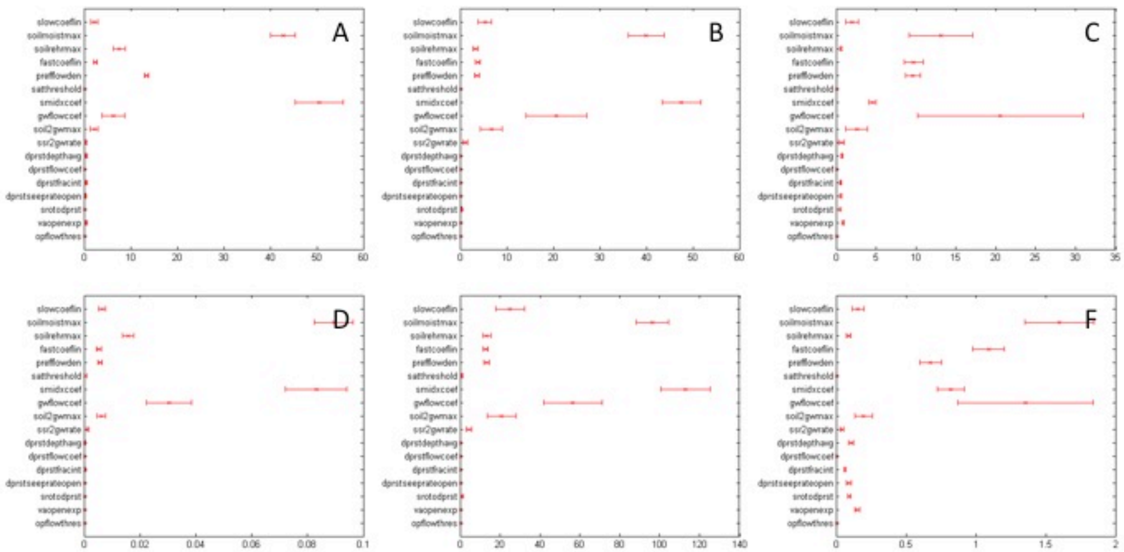

Figure 11. Function evaluation of the mean EE at Pond Creek near Deer Park, AL. (USGS streamgage 02479431).

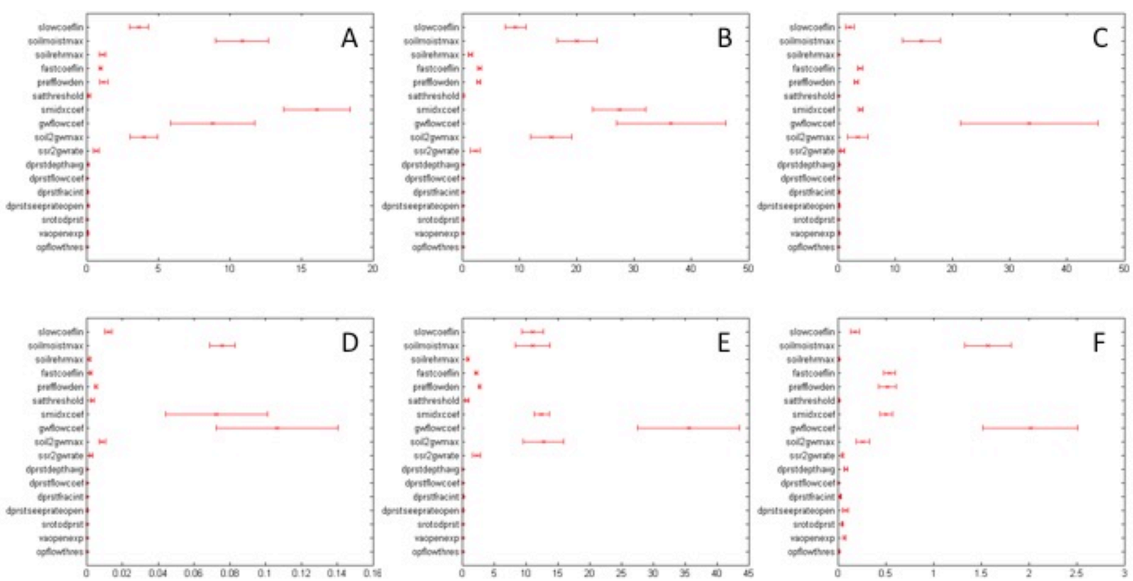

Figure 12. Function evaluation of the standard deviation EE at Pond Creek near Deer Park, AL. (USGS streamgage 02479431).

Results for Conecuh River at Fish River near Silver Hill, AL. (02378500)

The results of the Method of Morris global sensitivity performed at USGS streamgage station Fish River near Silver Hill, AL. (02378500) are shown in Figure 13, Figure 14, and Appendix A6. The μ sensitivity index highlighted 7 parameters impacted all functions, one parameter impacted hour out of 6 functions, and one parameter impacted one function (Figure 13A; Figure 13B; Figure 13C; Figure 13D; Figure 13E; Figure 13F). The water holding capacity of the soil profile parameter (soilmostmax) had medium or high sensitivity across all functions. The sensitivity of the non-linear coefficient controlling surface runoff parameter (smidxcoef) and the coefficient of groundwater flow into the stream network parameter (gwflowcoef) ranged from high to low across the functions. The parameter that routes preferential-flow down slope (fastcoeflin) and the preferential-flow pore density parameter (prefflowden) had medium or low impact on the functions. The parameters that route gravity-flow down slope (slowcoeflin) and soil water excess routed to groundwater reservoir (soil2gwmax) had little impact on all 6 metrics. The water holding capacity of the soil recharge zone parameter (soilrehrmax) had medium or low impact on every functions except the 10 % highest flow exceedance function and the TRMSE function. The parameter that characterizes the fraction of surface area that is open to depressions has low impact to the TRMSE output (Figure 13F).

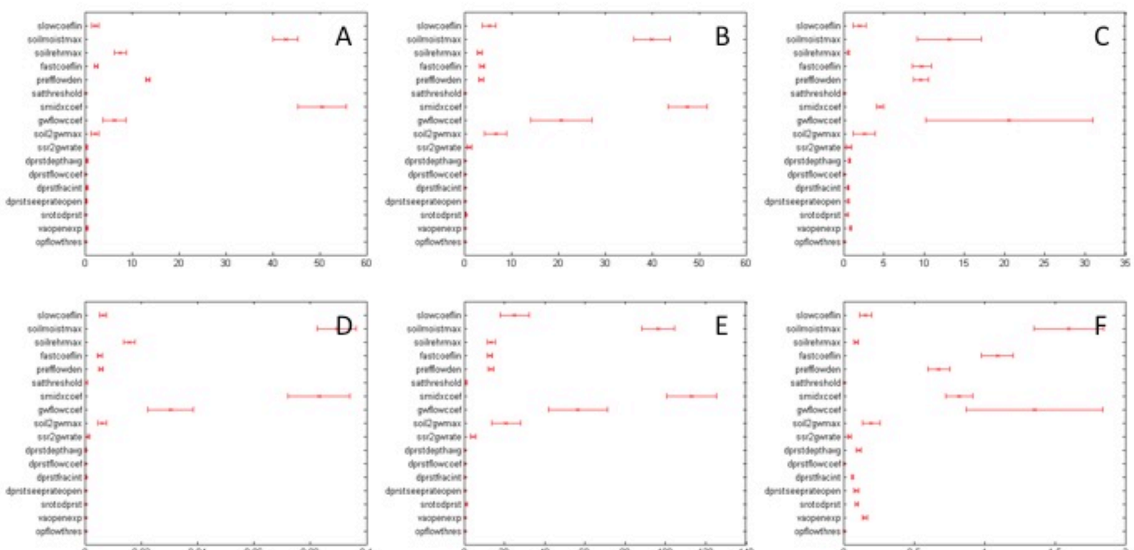

Figure 13. Function evaluation of the mean EE at Fish River near Silver Hill, AL. (USGS streamgage 02378500).

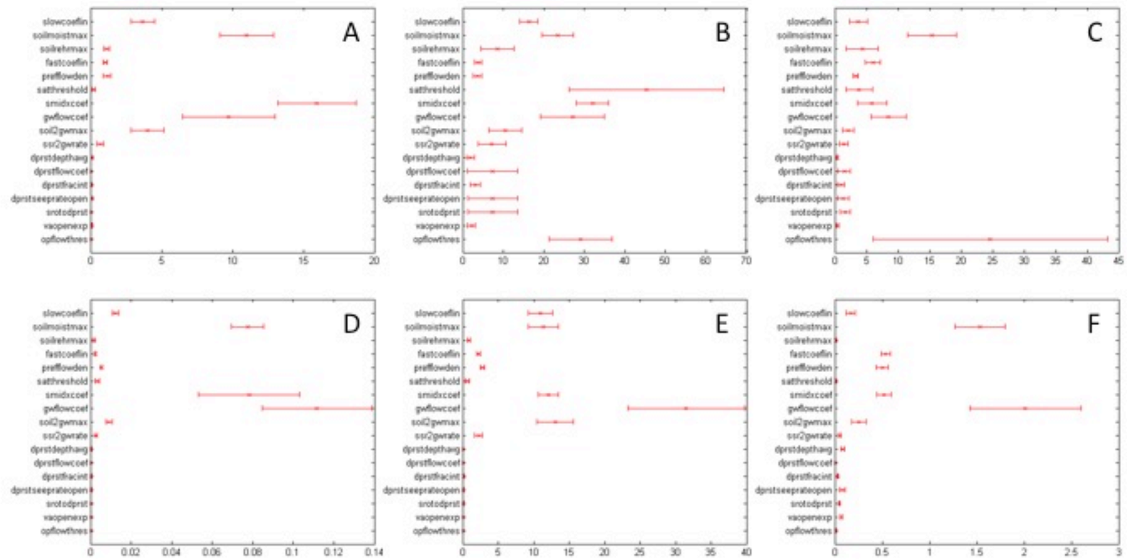

Figure 14. Function evaluation of the mean EE at Fish River near Silver Hill, AL. (USGS streamgage 02378500).

Results for Conecuh River at Murder Creek near Evergreen, AL. (02374500)

The results of the Method of Morris global sensitivity performed at USGS streamgage station Murder Creek near Evergreen, AL. (023784500) are shown in Figure 15, Figure 16, and Appendix A7. The μ sensitivity index highlighted 7 parameters impacted all functions, one parameter impacted hour out of 6 functions, and one parameter impacted one function (Figure 15A; Figure 15B; Figure 15C; Figure 15D; Figure 15E; Figure 15F). The water holding capacity of the soil profile parameter (soilmostmax) and the coefficient of groundwater flow into the stream network parameter (gwflowcoef) had high or medium impact on every function. The sensitivity of the non-linear coefficient controlling surface runoff parameter (smidxcoef) ranged from high to low across the functions. The parameter that routes preferential-flow down slope (fastcoeflin) and the preferential-flow pore density parameter (prefflowden) had medium or low impact on the functions. The parameters that route gravity-flow down slope (slowcoeflin) and soil water excess routed to groundwater reservoir (soil2gwmax) had little impact on all 6 metrics. The water holding capacity of the soil recharge zone parameter (soilrehrmax) had medium or low impact on every function except the 10 % highest flow exceedance function and the TRMSE function. The parameter that characterizes the fraction of surface area that is open to depressions has low impact to the TRMSE output (Figure 15F). The only difference between the sensitivity output from Murder Creek near Evergreen, AL. (023784500) and the Fish River near Silver Hill, AL. (02378500) was the ranking range of the coefficient of groundwater flow into the stream network parameter (gwflowcoef).

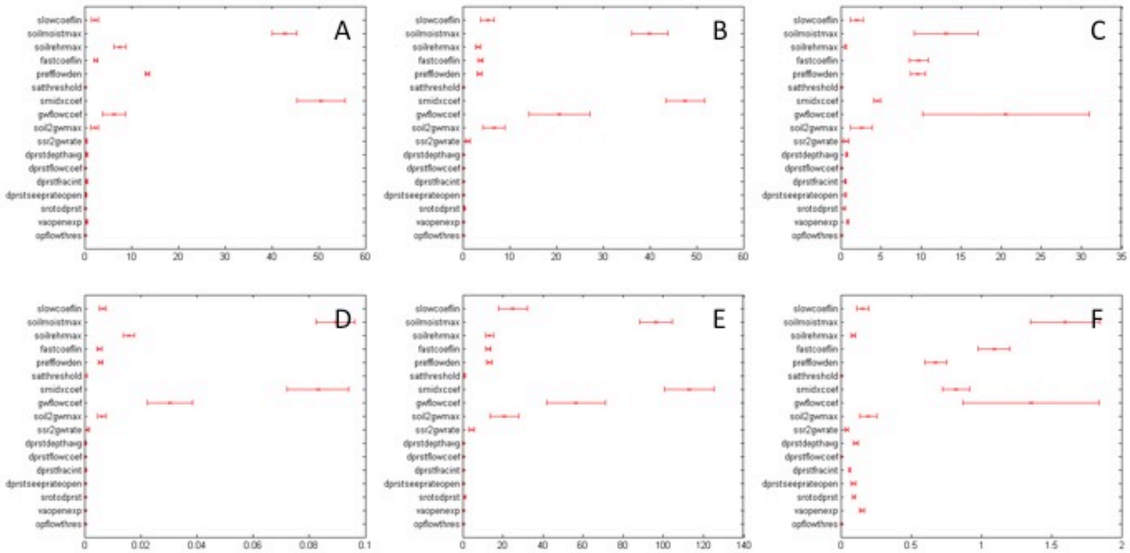

Figure 15. Function evaluation of the mean EE at Murder Creek near Evergreen, AL. (USGS streamgage 02374500).

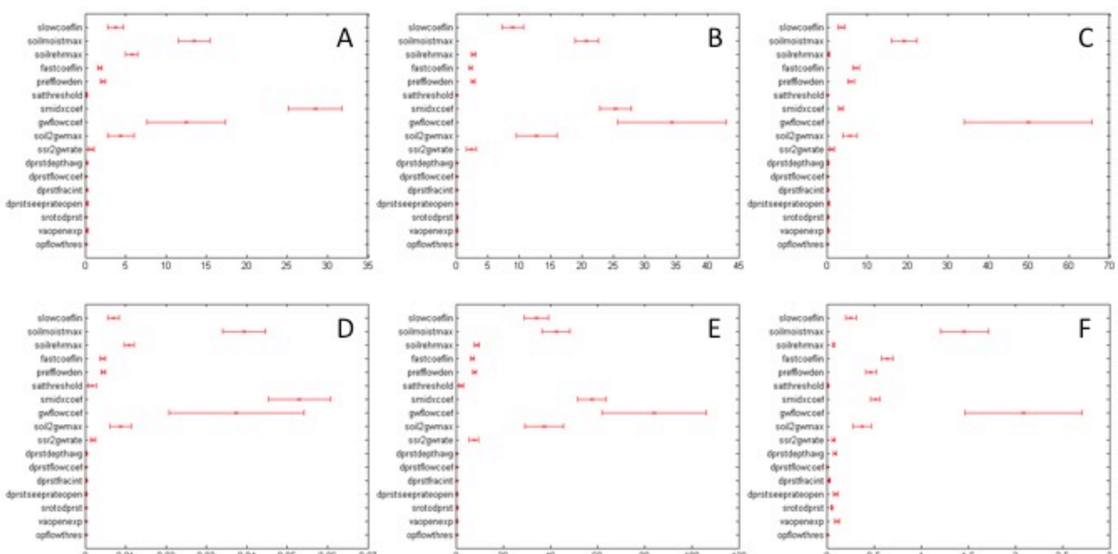

Figure 16. Function evaluation of the standard deviation EE at Murder Creek near Evergreen, AL. (USGS streamgage 02374500).

5.2 Identification of important parameters across mesoscale basins

Across the 7 mesoscale basins, we were able to identify the dominant parameters for the 6 different evaluation metrics. In general, the mesocale basins behave similar behavior across the study area, except USGS streamgage station Crooked Creek near Fairview, AL (02479980). This station has sensitivity to depression parameters due to its small drainage area.

Daily Flow Output

Eight model parameters are sensitive to daily flow error function (Table 5) and to the R^2 (Table 6), though the range of sensitivities varies across the mesoscale basins. The two different daily flow functsion highlight the same parameters had an impact on the model output. The highly significant parameters signify the importance to simulate the movement of water into the soil profile or over the impervious surface. The intermediate parameters indicate the level of importance for modeling the water movement of water from the top of the soil profile, through the soil column to the groundwater and eventually into the stream network. The parameters of low significance are associated with the routing requirement for each different flow regime. For example, slowcoeflin is the responsible parameter for routing of the daily flows, fastcoeflin routes the high flows, and soil2gwmax routes the low flows (Table 4).

Table 5. Visual interpretation of the μ sensitivity index of the daily flow error output from the Method of Morris global sensitivity performed at 7 headwater sites within the Gulf of Mexico Basin.

	Objective Function	02363000	02371500	02479800	02366996	02479431	02378500	02374500
slowcoeflin	All							
soilmoistmax	All							
soilrehrmax	All							
fastcoeflin	High							
prefflowden	High							
satthreshold	High							
smidxcoef	High							
gwflowcoef	Low							
soil2gwmax	Low							
ssr2gwrate	Low							
dprstdepthavg	Daily							
dprstflowcoef	Daily							
dprstfracinit	Daily							
dprstseeprateopen	Daily							
srotodprst	Daily							
vaopenexp	Daily							
opflowthres	Daily							

Table 6. Visual interpretation of the μ sensitivity index of R^2 output from the Method of Morris global sensitivity performed at 7 headwater sites within the Gulf of Mexico Basin.

	Objective Function	02363000	02371500	02479800	02366996	02479431	02378500	02374500
slowcoeflin	All							
soilmoistmax	All							
soilrehrmax	All							
fastcoeflin	High							
prefflowden	High							
satthreshold	High							
smidxcoef	High							
gwflowcoef	Low							
soil2gwmax	Low							
ssr2gwrate	Low							
dprstdepthavg	Daily							
dprstflowcoef	Daily							
dprstfracinit	Daily							
dprstseeprateopen	Daily							
srotodprst	Daily							
vaopenexp	Daily							
opflowthres	Daily							

High Flow Output

The 10% highest flow exceedance output highlights 7 parameters that are considered to impact the model (Table 7), and the RMSE output emphasizes 8 parameters impact the model (Table 8). The non-linear coefficient controlling surface runoff (smidx) is considered to have a high impact on both the high flow functions. The high flow functions had different parameters they consider highly impactful. The coefficient contributing groundwater flow into the stream network (gwflowcoef) parameter had a have high impact on the 10% highest flow exceedance output (Table 7). The non-linear coefficient controlling surface runoff (smidx) had a high impact on the RMSE output (Table 8).

The 10% highest flow exceedance output highlights 7 parameters as significant, whereas the RMSE output highlights 8 parameters as being impactful. The level of significance varies between the two high flow metric outputs. In general, the two highlight the importance of water holding capacity of the soil profile (soilmostmax), the non-linear coefficient controlling surface runoff (smidx), and coefficient contributing groundwater flow into the stream network (gwflowcoef) parameters as high or medium significance. The soilmoistmax parameter controls the amount of water that is held within the soil profile. The smidx and gwflowcoef parameters describe the movement of water into the stream network, either through imperious surface (smidx) or the groundwater (gwflowcoef). The parameters that route gravity-flow down slope (slowcoeflin), route preferential-flow down slope (fastcoeflin), characterize preferential-flow pore density (prefflowden), and route soil water excess to the groundwater reservoir (soil2gwmax) either are considered to have medium or low impact on the high flow metrics. Parameters with medium or low-level sensitivity are associated water in different flow regimes and the quick movement of water into the soil.

Table 7. Visual interpretation of the μ sensitivity index of 10% highest flow exceedance output from the Method of Morris global sensitivity performed at 7 headwater sites within the Gulf of Mexico Basin.

	Objective Function	02479431 (Map No.1)	02479800 (Map No.2)	02378500 (Map No.3)	02374500 (Map No.4)	02371500 (Map No.5)	02363000 (Map No.6)	02366996 (Map No.7)
slowcoeflin	All							
soilmoistmax	All							
soilrehrmax	All							
fastcoeflin	High							
prefflowden	High							
satthreshold	High							
smidxcoef	High							
gwflowcoef	Low							
soil2gwmax	Low							
ssr2gwrate	Low							
dprstdepthavg	Daily							
dprstflowcoef	Daily							
dprstfracinit	Daily							
dprstseeprateopen	Daily							
srotodprst	Daily							
vaopenexp	Daily							
opflowthres	Daily							

Table 8. Visual interpretation of the μ sensitivity index of RMSE output from the Method of Morris global sensitivity performed at 7 headwater sites within the Gulf of Mexico Basin.

	Objective Function	02479431 (Map No.1)	02479800 (Map No.2)	02378500 (Map No.3)	02374500 (Map No.4)	02371500 (Map No.5)	02363000 (Map No.6)	02366996 (Map No.7)
slowcoeflin	All							
soilmoistmax	All							
soilrehrmax	All							
fastcoeflin	High							
prefflowden	High							
satthreshold	High							
smidxcoef	High							
gwflowcoef	Low							
soil2gwmax	Low							
ssr2gwrate	Low							
dprstdepthavg	Daily							
dprstflowcoef	Daily							
dprstfracinit	Daily							
dprstseeprateopen	Daily							
srotodprst	Daily							
vaopenexp	Daily							
opflowthres	Daily							

Low Flow Output

The 50% lowest flow exceedance output highlights 7 parameters that are considered to impact the model (Table 9). The coefficient contributing groundwater flow into the stream network parameter (gwflowcoef) has high impact on the 50% lowest flow exceedance output (Table 9).

The TRMSE output highlights 7 parameters that are considered to impact the model (Table 10). The water holding capacity of the soil profile parameter (soilmostmax) and coefficient contributing groundwater flow into the stream network parameter (gwflowcoef) have high impact of the TRMSE output (Table 10).

The 50% lowest flow exceedance and TRMSE output highlight the same 7 parameters as having influence the low flow behavior. Both outputs signify that the contributing groundwater flow into the stream network parameter (gwflowcoef) has the highest impact on the low flow model behavior. This supports the notion the low flow is significantly controlled by the contribution of water from the groundwater reservoir. The water holding capacity of the soil profile parameter (soilmostmax), routing preferential-flow down slope (fastcoeflin), preferential-flow pore density (prefflowden), and the non-linear coefficient controlling surface runoff (smidx) parameters are of medium impact for the two low flow evaluation metric outputs. The intermediate parameters emphasize that importance quick movement of water into the soil and over impervious surface. The parameters associated with routing soil water excess to the groundwater reservoir (soil2gwmax) and routing gravity-flow down slope (slowcoeflin) have low impact for the low flow outputs. These parameters are associating with routing water in the soil profile.

Table 9. Visual interpretation of the μ sensitivity index of error of 50% lowest flow exceedance output from the Method of Morris global sensitivity performed at 7 headwater sites within the Gulf of Mexico Basin.

	Objective Function	02479431 (Map No. 1)	02479800 (Map No. 2)	02378500 (Map No. 3)	02374500 (Map No. 4)	02371500 (Map No. 5)	02363000 (Map No. 6)	02366996 (Map No. 7)
slowcoeflin	All							
soilmoistmax	All							
soilrehrmax	All							
fastcoeflin	High							
prefflowden	High							
satthreshold	High							
smidxcoef	High							
gwflowcoef	Low							
soil2gwmax	Low							
ssr2gwrate	Low							
dprstdepthavg	Daily							
dprstflowcoef	Daily							
dprstfracinit	Daily							
dprstseeprateopen	Daily							
srotodprst	Daily							
vaopenexp	Daily							
opflowthres	Daily							

Table 10. Visual interpretation of the μ sensitivity index of TRMSE output from the Method of Morris global sensitivity performed at 7 headwater sites within the Gulf of Mexico Basin.

	Objective Function	02479431 (Map No.1)	02479800 (Map No.2)	02378500 (Map No.3)	02374500 (Map No.4)	02371500 (Map No.5)	02363000 (Map No.6)	02366996 (Map No.7)
slowcoeflin	All							
soilmoistmax	All							
soilrehrmax	All							
fastcoeflin	High							
prefflowden	High							
satthreshold	High							
smidxcoef	High							
gwflowcoef	Low							
soil2gwmax	Low							
ssr2gwrate	Low							
dprstdepthavg	Daily							
dprstflowcoef	Daily							
dprstfracinit	Daily							
dprstseeprateopen	Daily							
srotodprst	Daily							
vaopenexp	Daily							
opflowthres	Daily							

6.0 Discussion

The sensitivity analysis allowed us to determine which parameters are more or less important for mesoscale basins within the Gulf of Mexico. The across evaluation functions analysis and the across mesoscale basin analysis determined in general 8 parameters are important.

6.1 Parameter sensitivity across evaluation functions

The sensitivity analysis was able to determine the importance of the 17 model parameters on the output for mesoscale basins in the Gulf of Mexico Basin. The 6 evaluation functions identified the same 7 model parameters as important across the mesoscale basins. These 7 model parameters include: routing coefficient for gravity-flow down slope (slowcoeflin), water holding capacity of the soil profile (soilmostmax), routing coefficient of preferential-flow down slope (fastcoeflin), preferential-flow pore density (prefflowden), non-linear coefficient controlling surface runoff (smidx), coefficient contributing groundwater flow into the stream network parameter (gwflowcoef), and routing soil water excess to the groundwater reservoir (soil2gwmax). In contrast, the daily flow error and RMSE metrics identified the water holding capacity of the soil recharge zone (soilrehrmax) as impactful on the output. In total, eight parameters were identified as impactful on the model output.

6.2 Sensitivity occurrence for the evaluation functions across the mesoscale basins

In order to understand the importance of model parameters across the mesoscale basin and across the evaluation functions I completed a frequency occurrence analysis at each station (Table 11). All levels of impact were equally weighed and scored, and then were summed across the evaluation functions. A combined score of 1 indicates that parameter was only sensitive to one evaluation function; whereas, a score of 6 indicates the parameter was sensitive across all evaluation functions. Any combined score above four was considered to have an overall significant impact on the model output.

Table 11. Frequency occurrence of sensitivity occurrence for the evaluation functions across the mesoscale basins.

		Southern Hilly Gulf Coastal Plain		Southern Pine Plains and Hills				
Parameter	**Associated Reservoir**	**02363000**	**02371500**	**02479800**	**02366996**	**02479431**	**02378500**	**02378500**
slowcoeflin	**subsurface**	1	6		6	6	6	6
soilmoistmax	**soil-zone**	6	6	6	6	6	6	6
soilrehrmax	**soil-zone**	4	4			4	4	4
fastcoeflin	**subsurface**	3	6	2	5	6	6	6
prefflowden	**subsurface**	4	6	3	5	5	6	6
satthreshold	**subsurface**							
smidxcoef	**impervious-zone**	6	6	5	6	6	6	6
gwflowcoef	**groundwater**	5	6	5	6	6	6	6
soil2gwmax	**soil-zone**	2	6		6	6	6	6
ssr2gwrate	**subsurface**							
dprstdepthavg	**depression**			3				
dprstflowcoef	**depression**							
dprstfracinit	**depression**			3				
dprstseeprateopen	**depression**			3				
srotodprst	**depression**			2				
vaopenexp	**depression**		1	3			1	1
opflowthres	**depression**							

In total, the frequency analysis identified 8 parameters to have an overall significant impact on the model output (Table 11). These 8 parameters are associated with the soil-zone, subsurface, impervious zone, and the groundwater reservoirs. The soil-zone reservoir gains water through precipitation and loses water from evapotranspiration. The subsurface reservoir controls the movement of water by preferential-flow or gravity-flow. The impervious-zone reservoir is associated with the quick movement of water over the land surface. The subsurface and impervious-zone reservoirs are associated with the fast movement of water overland and into the soil profile. The groundwater reservoir contributes water into the stream network. Therefore, the contribution of groundwater flow in considered impactful. The only reservoir not considered impactful was the depression storage reservoir. Therefore, water movement to depressions and the contribution of water from depressions into the stream network is not important. In general, the routing of water once it hits the land surface either to the stream network or through the soil profile into the groundwater reservoir are the controlling model parameters.

6.3 What the sensitivity analysis means for the automated calibration functions?

The 8 model parameters that were identified as important dominated different portions of the flow regime. The sensitivity analysis identified 8 parameters as important for daily flow, and the automated calibration technique identified 10 model parameters as sensitive to the daily flow function. The recommended model parameters from the sensitivity analysis and automated calibration technique only have 3 model parameters that overlap (slowcoeflin, soilmoistmax, and soilrehrmax). The 3 model parameters that overlap are from the first objective function of the automated calibration strategy. The fourth objective function of the automated calibration strategy, focused on daily flows, does not have a distinguishable effect on the model output.

For high flows, the sensitivity analysis identified 8 parameters as important whereas, the automated calibration technique only considered 4 model parameters as important to high flows. Within the 4 important parameters for the high flow function of the automated calibration (fastcoeflin, preflowden, satthreshold, and smidxcoef), only 3 model parameters (fastcoeflin, preflowden, and smidxcoef) were sensitive to the high flow regime. Therefore the parameter satthreshold, associated with water holding capacity of the gravity and preferential-flow reservoirs, did not have distinguishable effect on the model output.

The sensitivity analysis identified 7 parameters as important for low flow, whereas the automated calibration technique considered 3 model parameters as important to low flows. Of the 3 model parameters as important for the automated calibration technique (gwflowcoef, soil2gwmax, and ssr2gwrate), only 2 were considered to be impactful on the model output (gwflowcoef and soil2gwmax). Therefore the parameter ssr2gwrate, associated with routing water from the gravity to the groundwater reservoir, did not have a distinguishable effect on the model output for the Gulf of Mexico.

6.4 PRMS model simplicity for natural flows in the Gulf of Mexico

The sensitivity analysis was performed for the mesoscale basins with the Gulf of Mexico Basin and only focused on 17 model parameters within the PRMS model. These 17 parameters were selected because they were used during the automated calibration strategy and varied on the HRU dimension. For the purpose of this study, we discuss simplifying the modeling effort with respect to the 17 automated calibrated parameters. To simplify the modeling effort of natural flows in the mesoscale basins of the Gulf of Mexico Basin, there should be an emphasis on the 8 sensitive parameters (slowcoeflin, soilmoistmax, soilrehrmax, fastcoeflin, preflowden, smidxcoef, gwflowcoef, and soil2gwmax) instead of the recommended 17 from the automated calibration technique. Overall, more than half of the model parameters were identified to have little impact on stream flow. PRMS is composed hundreds of parameters that vary on different dimensions, such as month, segment, and sub basins. It is important to note, more than 8 parameters are necessary to calibrate the entire model.

6.5 Over-parameterization and equifinality and the effect on complex models

Over-parameterization and equifinality are issues that arise as a result of model complexity, and we observed that these issues are relevant to the mesoscale basins models within the Gulf of Mexico Basin simulated with PRMS. We observed that over-parameterization might be occurring because only 8 of the 17 recommended parameters are responsible for dominating the model output. Therefore, more parameters that necessary were being used for the automated calibration strategies that were actually necessary. Also, we observed the parameters that were highly impactful were dominated by interactions. Therefore, we can conclude that equifinality is an issue within the Gulf of Mexico PRMS model.

6.6 Limitations

There are multiple limitations to the approach that impacted the overall conclusion. The number of parameter considered for this study limited our ability to simplify the entire PRMS modeling effort for natural flows within the Gulf of Mexico. The focus on 7 mesoscale basins within 2 level IV ecoregions limits our ability to understand the hydrologic across the 8 different ecoregions within the Gulf of Mexico. Also, it limits our ability to understand the hydrology at larger streams within the region because different parameters could be more or less sensitive. We would expect the sensitivity of parameters also changing across spatial scales. Also, the assumed r value within the Method of Morris impacts the reliability of the model evaluation because this determines the number of model runs. The evaluation functions selected impact the ideal model output. The evaluation functions focused on capturing different portions of the flow regimes. However, an emphasis on the flow regimes also means we did not recognize other uncertainties within the model.

6.7 Lessons for managers

Before a modeling effort begins, it is important to determine the desired output and the amount of existing data present in the region of interest. It is important to weigh the output of interest with the amount of parameters required. Managers should be wary about choosing complex models because of the over-parameterization and equifinality issues that arise. After the model is chosen, but before the modeling effort begins, a sensitivity analysis should be performed. The sensitivity analysis provides information about which parameters are more or less important and which parameters are dominated by interactions. The parameters that are more important are the hydrologic processes the model views as dominant. It is important to note that the actual physical dominant hydrologic processes and the dominant model processes might be different. What a model is sensitive to and what is actually occurring can be two separate things. Managers should pay close attention to the level of interaction occurring between model parameters. When a model is dominated by interaction, it no longer is uniquely simulating hydrologic processes. An understanding of the model parameter can simplify the modeling effort.

7.0 Conclusion

It is important for scientists and managers to understand the natural flow regime in order to quantify the effects of human alterations. Therefore, we completed a sensitivity analysis to aid in model calibration. The global sensitivity analysis, Method of Morris, allowed us to determine which parameters are more or less important. After determining the impactful parameters, we were able to infer the important hydrologic processes within the Gulf of Mexico Basin PRMS model. The sensitivity analysis was performed at 7 mesoscale basins within the Gulf of Mexico Basin PRMS model. The sensitivity analysis identified 8 PRMS model parameters as highly impactful on stream flow prediction. These model parameters are associated with the soil-zone, subsurface, impervious zone, and the groundwater reservoir of the PRMS model. The main purpose of these parameters is to route water once it hits the land surface either to the stream network or through the soil profile into the groundwater reservoir. The sensitivity analysis identified the depression storage reservoir was not impactful, and therefore we conclude contribution of water from depression into the stream network is not important for this modeling effort.

The objective of this study was to understand unaltered drainages in the headwater basins of lower Alabama. Based on the sensitive parameters, we were able to infer that the movement of water into the soil and over the land surface is and important hydrologic processes for unaltered drainages in the headwater basins. We expect altering the land surface will greatly impact the stream flow response. By predicting flow at unaltered drainages, and applying the flow to altered drainage areas through the trading space for time approach we are able to understand how altered drainages have been changed.

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9.0 References

Arsenault, R., & Brissette, F. P. (2014). Continuous streamflow prediction in ungauged basins: The effects of equifinality and parameter set selection on uncertainty in regionalization approaches. *Water Resources Research*, *50*(7), 6135-6153.

Arthington, A.H., Bunn. S.E., Poff, N.L., and Naiman, R.J. (2006). The challenge of providing environmental flow rules to sustain river ecosystems. *Ecological Applications*, 16(4), 1311–1318.

Bárdossy, A. and Singh, S.K. (2008). Robust estimation of hydrological model parameters. *Hydrology and Earth System Sciences*, 12(6), 1273–1283.

Beckham III, E. C. (1977). A Report on the Escata WPA River System of Alabama and Mississippi. *Southeastern Fishes Council*, Proceedings 2:1-4.

Beven, K. (1993). Prophecy, reality and uncertainty in distributed hydrological modeling. *Advances in Water Resources*, 16(1), 41–51.

Carlisle, D. M., Falcone, J., Wolock, D. M., Meador, M. R. and Norris, R. H. (2010). Predicting the natural flow regime: models for assessing hydrological alteration in streams. *River Research and Application*, 26(2) 118–136. doi: 10.1002/rra.1247

Cibin, R., Athira, P., Sudheer, K. P. and Chaubey, I. (2014). Application of distributed hydrological models for predictions in ungauged basins: a method to quantify predictive uncertainty. *Hydrological Processes*, 28(4) 2033–2045. doi: 10.1002/hyp.9721

Campolongo, F., Cariboni, J., and Saltelli, A. (2007). An effective screening design for sensitivity analysis of large models. *Environmental Modeling & Software*, 22(10), 1509-1518.

Duan, Q., Sorooshian, S., and Gupta, V. K. (1994). Optimal use of the SCE-UA global optimization method for calibrating watershed models. *Journal of hydrology*, 158(3), 265-284.

Fekete, B. M., Wisser, D., Kroeze, C., Mayorga, E., Bouwman, L., Wollheim, W.M., and Vörösmarty, C. (2010). Millennium Ecosystem Assessment scenario drivers (1970–2050): climate and hydrological alterations. *Global Biogeochemical Cycles*, 24(4).

Fox, D. A., Hightower, J. E., and Parauka, F. M. (2000). Gulf sturgeon spawning migration and habitat in the Choctawhatchee River system, Alabama–Florida. *Transactions of the American Fisheries Society*, 129(3), 811-826.

Gupta, H. V., Sorooshian, S., and Yapo, P.O. (1998). Toward improved calibration of hydrologic models: Multiple and noncommensurable measures of information. *Water Resources Research*, 34(4), 751–763.

Hay, L. E., and Umemoto, M. (2007). Multiple-objective stepwise calibration using Luca. U.S. Geological Survey.

Kim, S. M., Benham, B. L., Brannan, K. M., Zeckoski, R. W., and Doherty, J. (2007). Comparison of hydrologic calibration of HSPF using automatic and manual methods. *Water resources research*, *43*(1).

Leavesley, G. H., Restrepo, P. J., Markstrom, S. L., Dixon, M., and Stannard, L. G. (1996). The modular modeling system (MMS): User's manual. *US Geological Survey Open-File Report*, *96*(151,142).

Lewis, M. A., Weber, D. E., and Stanley, R. S. (1998). Comparative animal and plant toxicities of 10 treated effluents discharged to near-coastal areas of the Gulf of Mexico. *Water Environment Research*, 1108-1117.

Markstrom, S.L., Niswonger, R. G., Regan, R. S., Prudic, D. E., and Barlow, P. M. (2008). GSFLOW, Coupled Ground-Water and Surface-Water Flow Model Based on the Integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005).

McCuen, R. H. (1973). The role of sensitivity analysis in hydrologic modeling.*Journal of Hydrology*, *18*(1), 37-53.

Morris, M. D. (1991). Factorial sampling plans for preliminary computational experiments. *Technometrics*, *33*(2), 161-174.

Pianosi, F., Sarrazin, F., and Wagener, T. (2014). Introduction to the SAFE Matlab Toolbox for Global Sensitivity Analysis.

Pianosi, F., F. Sarrazin, and T. Wagener (2015), The Sensitivity Analysis For Everyone (SAFE) 1184 Toolbox, accessed at < http://www.bris.ac.uk/cabot/resources/safe-toolbox/> on 13 February 2015.

Sterling, S. M., Ducharne, A., and Polcher, J. (2013). The impact of global land-cover change on the terrestrial water cycle. *Nature Climate Change*, *3*(4), 385-390.

Thornton, P. E., Thornton, M. M., Mayer, B. W., Wilhelmi, N., Wei, Y., Devarakonda, R., and Cook, R. (2012). Daymet: Daily surface weather on a 1 km grid for North America, 1980-2008. Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center for Biogeochemical Dynamics (DAAC), 1.

Van Griensven, A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, M., and Srinivasan, R. (2006). A global sensitivity analysis tool for the parameters of multi-variable catchment models. *Journal of hydrology*, *324*(1), 10-23.

van Werkhoven, K., Wagener, T., Reed, P., and Tang, Y. (2008). Characterization of watershed model behavior across a hydroclimatic gradient. *Water Resources Research*, *44*(1).

Vörösmarty, C. J., Green, P., Salisbury, J., and Lammers, R. B. (2000). Global water resources: vulnerability from climate change and population growth.*science*, *289*(5477), 284-288.

Vrugt, J. A., Gupta, H. V., Bouten, W., and Sorooshian, S. (2003). A Shuffled Complex Evolution Metropolis algorithm for optimization and uncertainty assessment of hydrologic model parameters. *Water Resources Research*,*39*(8).

Wagener, T., Van Werkhoven, K., Reed, P., and Tang, Y. (2009). Multiobjective sensitivity analysis to understand the information content in streamflow observations for distributed watershed modeling. *Water resources research*,*45*(2).

Young, C. A., Escobar‐Arias, M. I., Fernandes, M., Joyce, B., Kiparsky, M., Mount, J. F., ... and Yates, D. (2009). Modeling the hydrology of climate change in California's Sierra Nevada for subwatershed scale adaptation1.

10.0 Appendix

A1through A7 are the visual interpretation results of the μ and σ sensitivity index for the Method of Morris global sensitivity. The table of each appendix is the μ sensitivity index, and the bottom table is the σ sensitivity index**.** Red indicates high importance, yellow denotes medium importance, green signals low importance, and white indicates no/little importance.

Appendix A1. Visual interpretation of the Method of Morris global sensitivity performed at USGS streamgage station Crooked Creek near Fairview, AL. (02479980)

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

Appendix A2. Visual interpretation of the Method of Morris global sensitivity performed at USGS streamgage station Pea River near Ariton, AL. (02363000)

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

Appendix A3. Visual interpretation of the Method of Morris global sensitivity performed at USGS streamgage station Conecuh River at Brantley, AL. (02371500).

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

Appendix A4. Visual interpretation of the Method of Morris global sensitivity performed at USGS streamgage Alaque Creek near Pleasant Ridge, FL. (02366996).

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

Appendix A5. Visual interpretation of the Method of Morris global sensitivity performed at USGS streamgage Pond Creek near Deer Park, AL. (02479431).

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

Appendix A6. Visual interpretation of the Method of Morris global sensitivity performed at USGS streamgage Fish River near Silver Hill, AL. (02378500).

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

Appendix A7. Visual interpretation of the Method of Morris global sensitivity performed at USGS streamgage Murder Creek near Evergreen, AL. (02374500).

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						

	Objective Function	Daily	R^2	High	RMSE	Low	TRMSE
slowcoeflin	All						
soilmoistmax	All						
soilrehrmax	All						
fastcoeflin	High						
prefflowden	High						
satthreshold	High						
smidxcoef	High						
gwflowcoef	Low						
soil2gwmax	Low						
ssr2gwrate	Low						
dprstdepthavg	Daily						
dprstflowcoef	Daily						
dprstfracinit	Daily						
dprstseeprateopen	Daily						
srotodprst	Daily						
vaopenexp	Daily						
opflowthres	Daily						